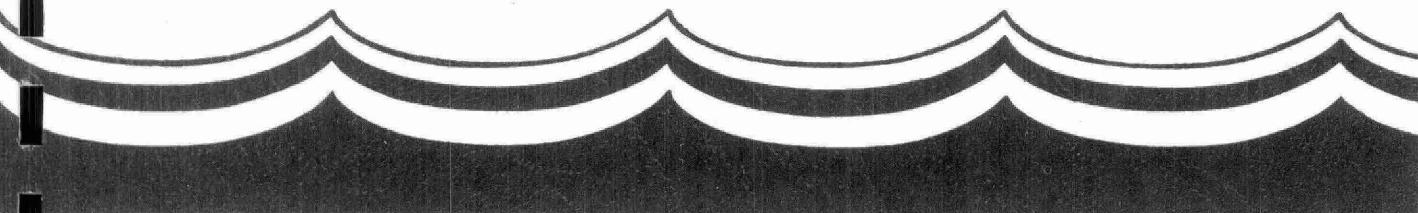


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STRATFORD/AVON RIVER **ENVIRONMENTAL MANAGEMENT PROJECT**



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STRATFORD-AVON RIVER ENVIRONMENTAL
MANAGEMENT PROJECT

EXPERIMENT TO CONTROL AQUATIC PLANT GROWTH
BY SHADING

Technical Report S-14

Prepared by:

L. Demal
M. Fortin

May, 1984

PREFACE

This report is one of a series of technical reports resulting from work undertaken as part of the Stratford/Avon River Environmental Management Project (SAREMP).

This three-year project was initiated in April 1980, at the request of the City of Stratford. The SAREMP is funded by the Ontario Ministry of the Environment. The purpose of the project is to provide a comprehensive water quality management strategy for the Avon River Basin. In order to accomplish this considerable investigation, monitoring and analysis has taken place. The outcome of these investigations and field demonstrations will be documented strategy outlining the program and implementation mechanisms most effective in resolving the water quality problems now facing residents of the basin. The project is assessing urban, rural and in-stream management mechanisms for improving water quality.

This report results directly from the aforementioned investigations. It is meant to be technical in nature and not a statement of policy or program direction. Observations and conclusions are those of the authors and do not necessarily reflect the attitudes or philosophies of the agencies and individuals affiliated with the project. In certain cases the results presented are interim in nature and should not be taken as definitive until such time as additional support data is collected.

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ABSTRACT

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Eutrophication due to nutrient enrichment is one of the most complex and difficult water quality problems encountered in the Avon River. It has been determined that phosphorus is the primary factor limiting levels of aquatic plant growth. Other factors, however, tend to promote luxuriant growth levels. These include a shallow flow depth, a cobble and stone substrate along much of the streambed and the lack of light limiting shade trees along the river banks. The study described here was initiated to determine the effectiveness of tree shading in controlling growth of aquatic plants.

The study involved two components. The first was a controlled experiment using an artificial shade canopy over an experimental reach and an open control reach. Intensive biomass sampling was conducted in these reaches throughout the growing season. In addition, water quality samples and physical surveys were taken to characterize ambient conditions.

The second component of the study involved a survey of aquatic plant growth in areas that were already shaded by overhanging trees. As in the first component, biomass samples were taken and physical data recorded to describe growth conditions.

The artificial shade canopy provided 71% shading on average while bank-side trees provided between 48% and 83% shade. In both cases, marked biomass reductions were noted under the shade, particularly during the peak growth periods. Under experimental conditions, biomass reduction by shading averaged 70%. Under natural conditions, reductions ranged between 60% and 74%. Reductions were most notable during the peak growth period in May declining in significance during the period of low, warm summer flows (June, July, August).

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1.0 INTRODUCTION

In 1980 and 1981, several studies were conducted under the auspices of the Stratford-Avon River Environmental Management Project (SAREMP) to investigate the extent of nuisance aquatic plant growth and the attendant oxygen depletion in the Avon River and to determine possible solutions to the problem (S3, S4, S5, S6, S7, S9*). It was found that the Avon River provides ideal conditions for the growth of nuisance aquatic plants, especially the filamentous algae Cladophora glomerata and Potamogeton sp. Up to 55 tons of dense plant growth can be in the river downstream of Stratford in mid-summer (S-3). In addition to depleting dissolved oxygen concentrations, excessive plant growth impairs fish habitat, is unsightly, and may impair downstream water quality as it dies and decays.

The growth of Cladophora sp. and Potamogeton sp. is influenced by several factors: the nutrients available to plants, particularly phosphorus; the amount of available sunlight; water temperature; the depth and type of channel bottom; and the velocity of stream flow. Theoretically, any one of these could act as a limiting factor inhibiting plant growth. However, modelling results for the Avon River indicate that the most effective biomass control can be obtained by limiting the instream phosphorus concentrations and by restricting the amount of sunlight which reaches the plants (S-6).

* SAREMP technical report references are located on the back cover. These reports are referred to here by their report number.

In the Avon River, phosphorus concentrations can be reduced in the near future by additional treatment of Stratford's sewage effluent, by control of rural erosion, and by improvement in livestock and manure management techniques. In the long-term, however, shading may provide the most effective direct control of nuisance aquatic biomass. In 1982, an experiment was undertaken to control aquatic plant growth by shading in order to verify computer modelling results. This report documents the methods and results of this experiment. The management applications of these results are addressed in a companion report, "Design of an Arboreal Shade Project to Control Aquatic Plant Growth", (S-15).

2.0 STUDY SITE LOCATIONS

The field work in this study had two components: the artificial shading experiment was the main component, while field observations of biomass growth in naturally shaded areas were used to supplement experimental data. Several potential study sites were identified for the artificial shading experiment using aerial photographs and field observations. A single location was chosen in the lower basin (Figure 1) based on the following criteria: an area that had supported luxuriant biomass growth in past years; similarity of channel slope, stream bed material, channel morphology, and exposure to sunlight over the entire site; accessibility for field work; and land-owner cooperation. The experimental reach was located approximately 300 metres upstream of the control reach. To measure aquatic biomass growing under natural shade, four sampling sites with natural tree canopies overhanging the river were identified downstream of the Avon River mouth on the North Thames River (see Figure 1).

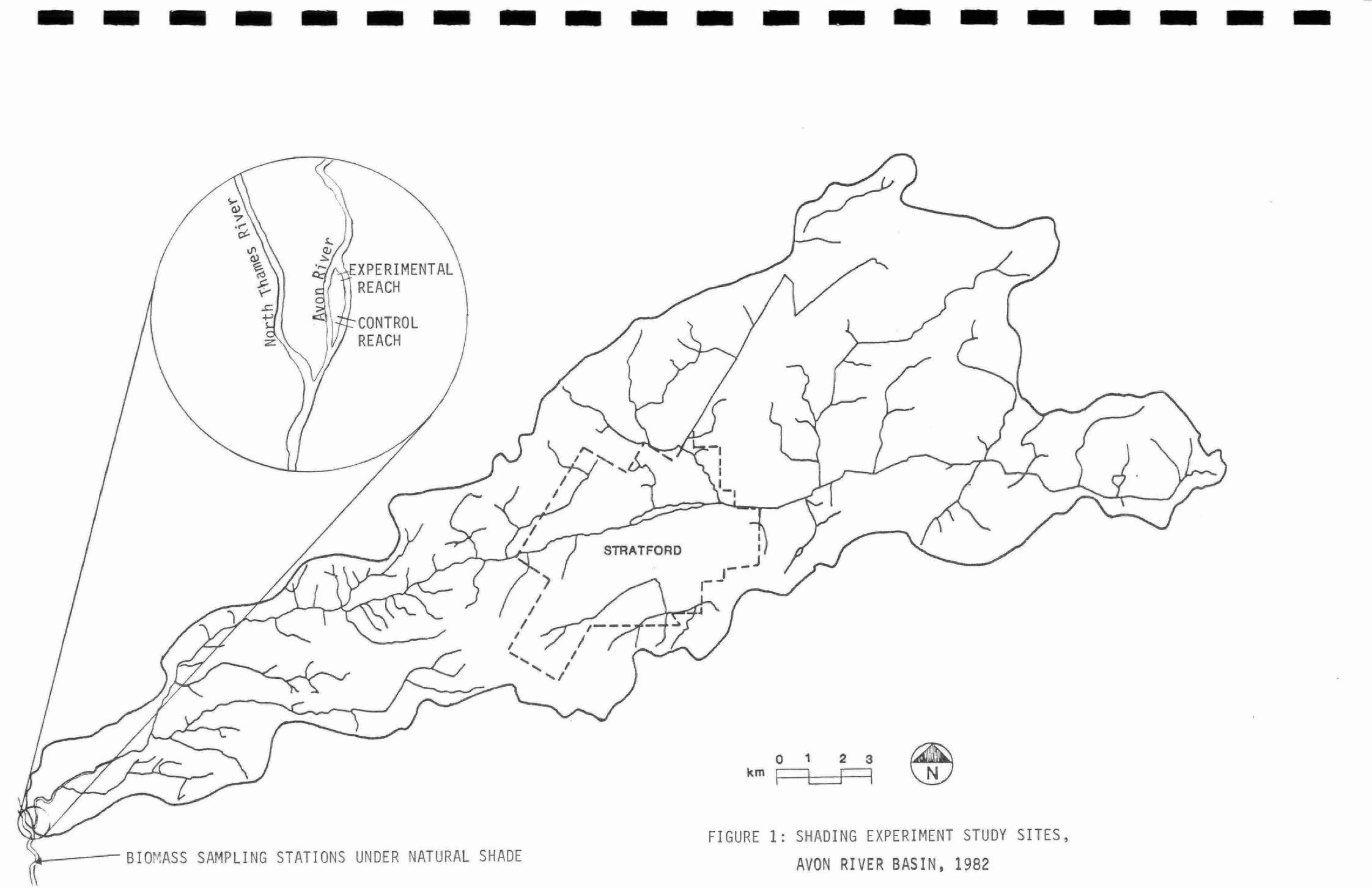


FIGURE 1: SHADING EXPERIMENT STUDY SITES,
AVON RIVER BASIN, 1982

3.0 METHODS

3.1 Artificial Shading Experiment

Artificial shading was used at one site on the lower Avon River over the full field season to enable detailed continuous monitoring of shaded and unshaded biomass growth under controlled conditions. Experimental and control reaches were selected so as to ensure similarity of physical channel characteristics between the two sites. A greenhouse product, Propex Shade Cloth, was used to shade the experimental reach. This material, a woven synthetic cloth, was designed to provide 73% shade. It measured 24 feet wide by 150 feet long and was suspended about 5 feet above the water's surface on a heavy wire frame supported by T-bars implanted along either bank (Figure 2). To help eliminate incomplete shading along the southeast and southwest edges, additional shade cloth was suspended along these two sides to the water's surface. The shade canopy and its supporting frame were constructed by April 30, prior to the establishment of any heavy algal growth.

Biomass sampling was done twice weekly during the expected peak growth period, May 10 to June 3, and weekly for the remainder of the field season, June 10 to September 29, for a total of 24 sampling days. Sampling was done by cropping 15 one-square-foot cells in each of the experimental and control study reaches on each sampling date. The selection of cells was based on a randomized block design, without replication (i.e. any cell within each reach was sampled only once over the growing season). Three cells were randomly selected from each of the 5 blocks in each reach. The total available sampling area measured 20 feet wide by 125 feet long; each block was 20 feet wide by 25 feet long (figure 3)*.

* Imperial units are cited here in keeping with the sampling equipment, the Surber Sampler, which measures 1 foot by 1 foot.

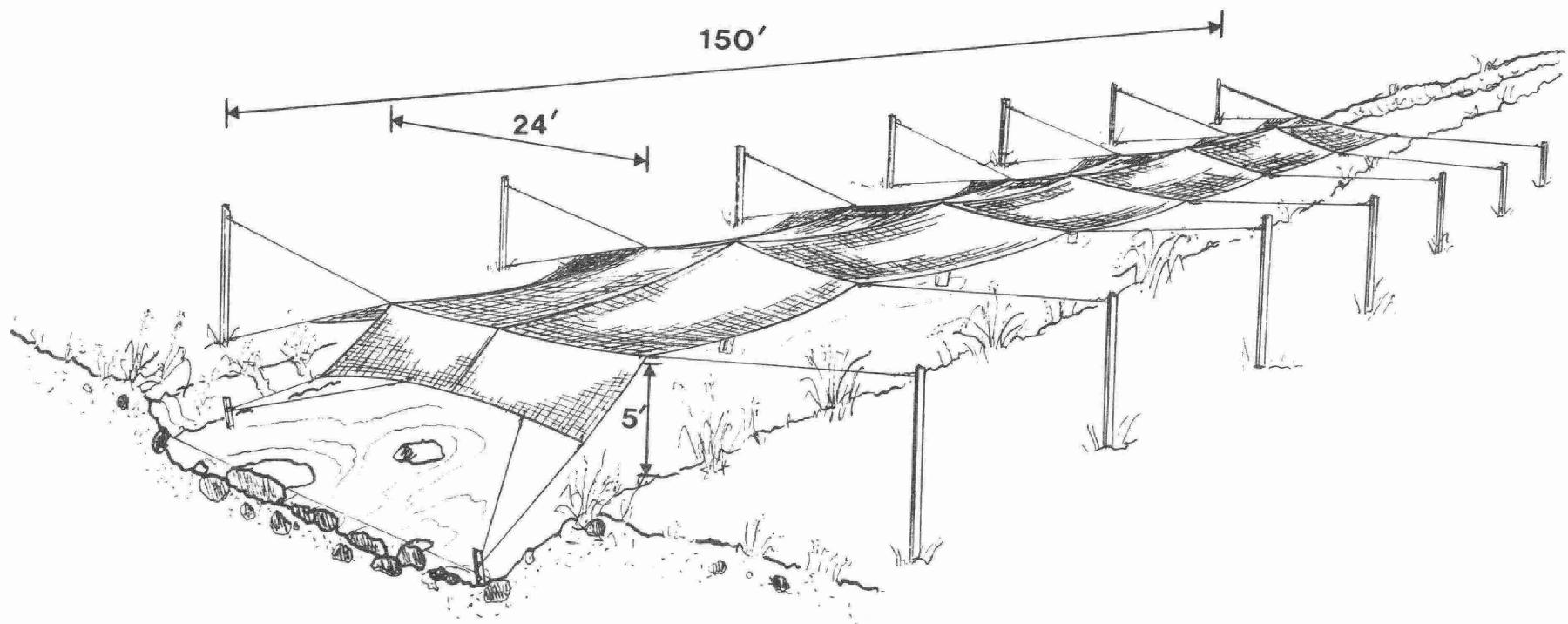


FIGURE 2: SHADE CANOPY INSTALLATION AT THE EXPERIMENTAL REACH, AVON RIVER, 1982

Samples were obtained for each cell by manually cropping all plant biomass found within the one-foot-square collection area of a Surber sampler. To minimize bias from subsequent cropping of trailing algae filaments downstream of the sampled area, a number of downstream cells were eliminated from the total area available for sampling, for each cell sampled. The number of cells eliminated varied with the average length of algal filaments (up to 10 feet long) on each sampling date. The cropped biomass sample was collected in the Surber sampler net and washed of silt, organisms and debris. The plants were identified and separated into two representative groups: (i) Cladophora glomerata and (ii) 'others', which included Potamogeton sp., Ceratophyllum demersum, Elodea canadensis, and Hydrodictyon sp. The samples were air-dried and then oven-dried at approximately 100°C for 2 to 4 hours, until constant dry weights were obtained and recorded.

Through the peak growth season in May and early June, plant tissue samples were collected for an analysis of total nitrogen and total phosphorus. For these samples, small amounts of tissue were cropped at points throughout each reach. Three replicates were prepared for each reach and immediately oven-dried. These were then ground and sent to the Vegetation/Soils Laboratory, MOE (Rexdale) for analysis.

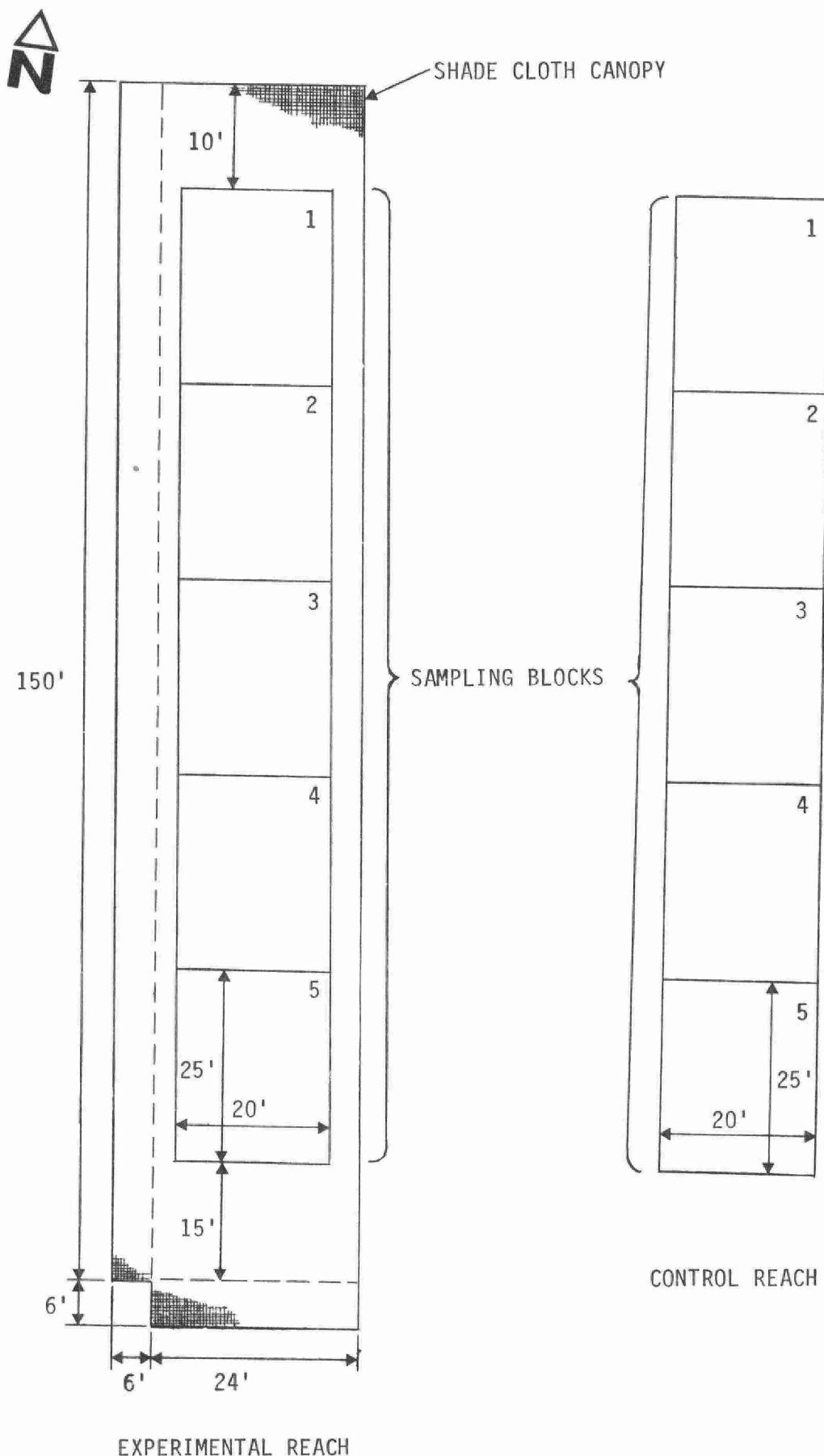


FIGURE 3: SAMPLING BLOCK DESIGN FOR THE EXPERIMENTAL AND CONTROL REACHES, AVON RIVER, 1982

Streambed elevations were surveyed in detail using transects spaced 3.05 m (10 ft) apart. Flow velocities and depths were also surveyed along the same transects during a period of relatively low flows (about 0.5 m³/sec on May 14 and 15). Flow velocities were measured using a Pigmey-Gurley Flow Meter.

Water quality samples were collected over the sampling period. These were submitted within 24 hours of collection for analysis to the MOE laboratory in the Southwestern Region Office (London), and were analysed for phosphorus and nitrogen species.

Light measurements were made in the open, below the shade canopy and just below the water surface using an underwater quantum sensor (LI-Cor Model 189, Lambda Instruments). The light sensor measures photosynthetically available light in the 400-700 nm range.

Individual temperature readings were recorded at both the experimental and control sites on each sampling date. This temperature data was supplemented with simulated mean daily water temperature data. A water temperature model developed for the Avon River was used for this purpose.* This model simulates mean daily water temperatures for the Avon River using air temperature and solar radiation data.

3.2 Field Observations at Naturally-Shaded Sites

To obtain information on the effectiveness of natural shade in controlling aquatic weed growth, field observations at naturally-shaded sites were made. Four suitable sites were found downstream of the mouth of the Avon River on the Thames River. Biomass samples were obtained during the peak season of algal growth

* M. Fortin, "Simulation of Missing Meteorologic Data for Purposes of Water Quality Modelling", File Report, SAREMP, February 25, 1982.

in May and early June. Three representative samples were selected from areas under overhanging tree canopies as well as from adjacent areas in open sunlight, providing a total of six samples for each site. Sampling and drying procedures used are documented in the preceding section.

In addition, the following physical characteristics were measured to help characterize the aquatic environment: flow depth, flow velocity, percentage light penetration above and below the water surface, percentage algae cover, and channel bottom substrate.

4.0 RESULTS AND DISCUSSION

4.1 Artificial Shading Experiment

Study reaches for the artificial shading experiment were straight and had relatively uniform rectangular channels (see Figure 4). Channel substrate consisted primarily of gravel, cobbles and some boulders over sand and clay. Under summer baseflow conditions, water depths throughout the sampling areas were generally less than 0.5 m.

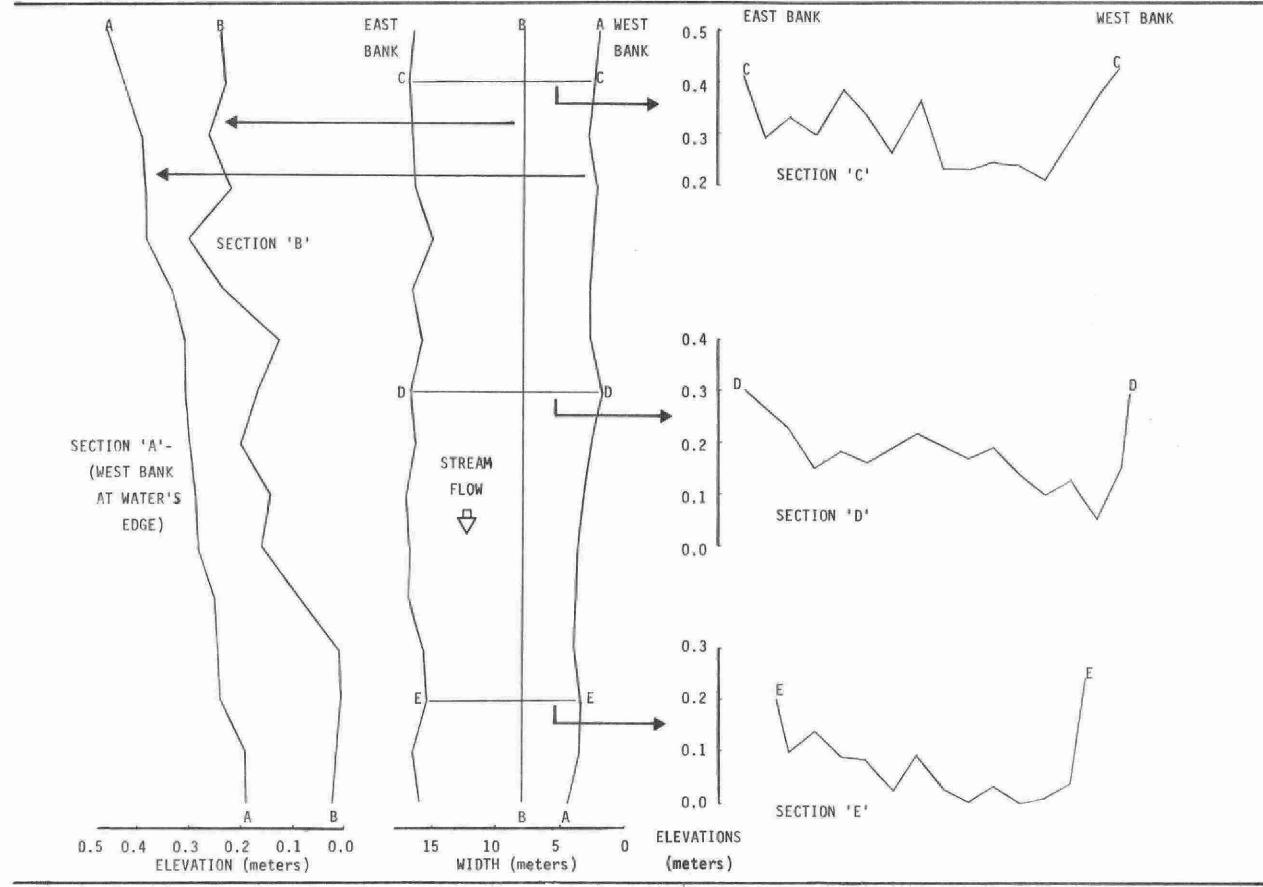
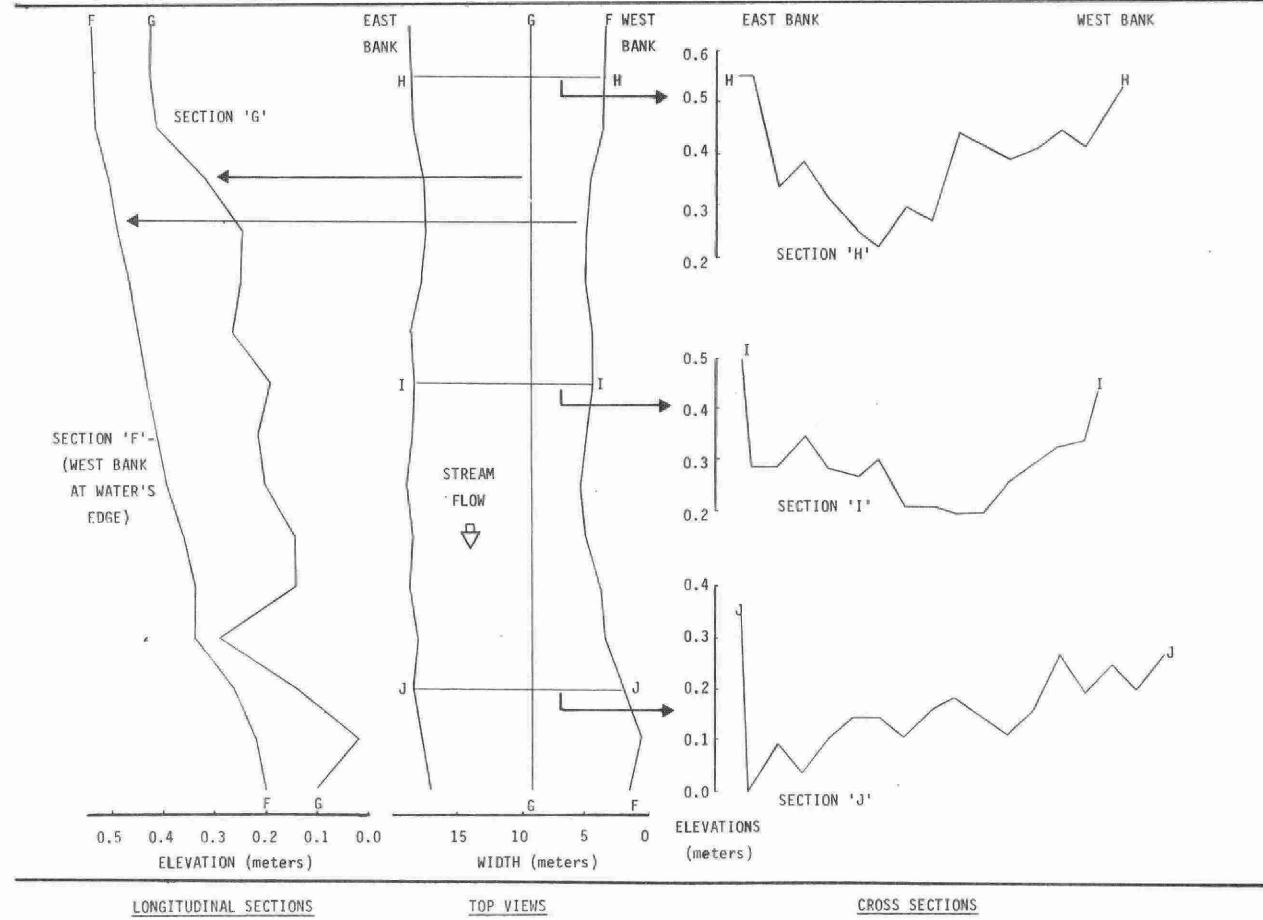
Control Reach**Experimental Reach**LONGITUDINAL SECTIONSTOP VIEWSCROSS SECTIONS

FIGURE 4: PHYSICAL SURVEY RESULTS FOR THE EXPERIMENTAL AND CONTROL REACHES, AVON RIVER

The rectangular nature of the channels at both sites, combined with the hydraulic (back-water) impact of the aquatic plants, ensured that flow depths were relatively uniform across each study reach throughout the sampling period. Areas of streambed were not, therefore, left dry at any time due to low-flow conditions. Channel slopes at both reaches were approximately 0.6%.

Flow velocity was highly variable throughout each reach due to turbulence caused by cobbles and boulders. During a period of relatively low flow, flow velocity and depth were surveyed in detail to verify that the two reaches were physically similar. Statistics derived from the survey, in Table 1, are based on measurements within the sampling areas. Flow velocity and depth tend to be somewhat lower in the control reach for the surveyed low-flow conditions; however, these differences are not great.

TABLE 1: Comparison of Physical Characteristics
of the Control and Experimented Reaches,
Avon River, May 14-15, 1982

	Control	Experimental
Survey Date	May 15	May 14
Flow Volume (m ³ /sec)	0.49	0.40
Flow Velocity (m/sec)		
mean	0.864	1.000
std. dev.	0.484	0.431
Flow Depth (cm)		
mean	14.74	16.76
st. dev.	4.55	5.66

Light readings were made in May under a variety of meteorologic conditions and at various times between 1100 and 1800 hours. In the open, light levels ranged between 1300 and 3600 micro-Einsteins $m^{-2}sec^{-1}$). Readings below the shade canopy varied between 21.4% and 36.1% of the unshaded light readings. The average reduction of light by the shade canopy was 70.8%. Underwater readings ranged between 60% and 77% of those recorded above the water surface for both open and shaded conditions.

Temperature readings were highly variable due to the influences of incident sunlight and time of day on water temperature in this shallow stream. Mean monthly temperatures for May, June, July and August were $21.5^{\circ}C$, $20.1^{\circ}C$, $26.8^{\circ}C$ and $19.6^{\circ}C$ respectively.

Sample sizes for these means are quite small - 18, 10, 3 and 4 observations respectively for May, June, July and August.

Simulated mean daily water temperature are plotted in Figure 5. Observed data are superimposed on the simulated data series. The overall trends of the two data sets are comparable. Individual deviation of observed data from simulated means range up to $6^{\circ}C$. This is not surprising considering that individual observations will vary markedly with time of day. The daily variation in water temperature monitored in the Avon River in 1980 at a station upstream of the experimental site averaged $5.3^{\circ}C$ and ranged up to $10.8^{\circ}C$.* On May 14, 1982 a $7.5^{\circ}C$ variation in water temperature was observed at the experimented site. Based on simulated data, monthly means are $20.5^{\circ}C$, $18.5^{\circ}C$, $24.0^{\circ}C$, $21.4^{\circ}C$ and $17.0^{\circ}C$ respectively for May, June, July, August and September. Temperatures between $15^{\circ}C$ and $20^{\circ}C$ favour Cladophora growth.**

* D. Hayman, M. Fortin, M. Seto, "Design of an Arboreal Shade Project to Control Aquatic Plant Growth", SAREMP Technical Report S-15, March 1983.

** R. Walker, D. G. Weatherbe, K. Wilson, "Aquatic Plant Model - Derivation and Application", "Grand River Basin Water Management Study Technical Report Series, Report # 14, November, 1982.

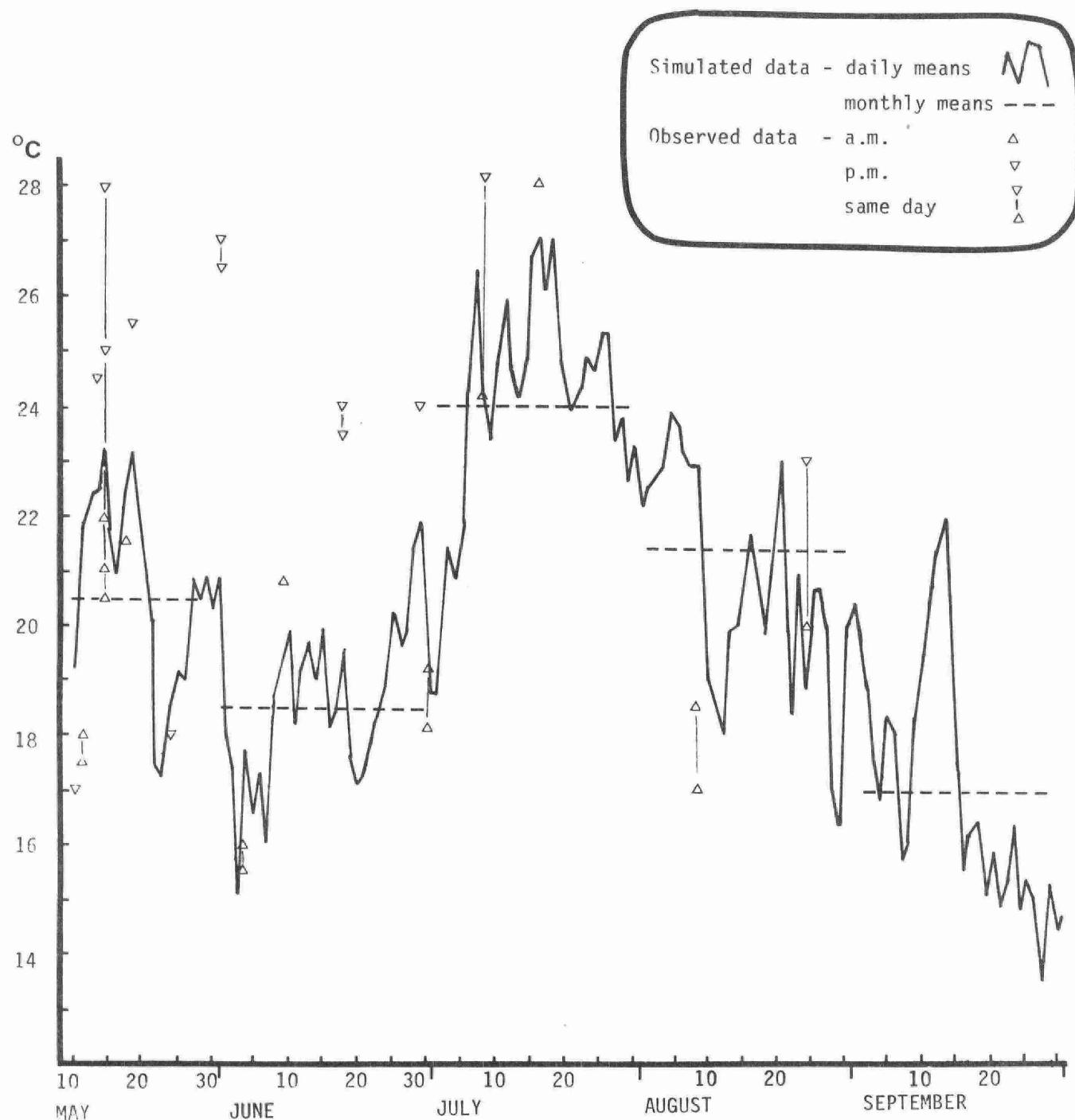


FIGURE 5: SIMULATED AND OBSERVED WATER TEMPERATURES IN
THE AVON RIVER, 1982

Mean biomass densities (gm dry weight m^{-2}) from the detailed continuous monitoring of the shaded experimental and the unshaded control reaches are outlined in Table 2 and Figure 6. Over the entire growing season approximately 5% of the total biomass by weight was composed of plant species other than Cladophora sp. The main growth period for Cladophora sp., the nuisance aquatic plant of prime concern in the Avon River, extended from May 10 to mid-June, with the peak growth occurring around May 24. The other plants, Potamogeton natans., Elodea canadensis, Ceratophyllum demersum, and Hydrodictyon sp., were present in small amounts from July 29 to the end of the field season. As a result of a 71% reduction in light under the shade canopy, aquatic weed growth was reduced by approximately 70%, from a seasonal average density of 37.2 gm dry weight m^{-2} at the control site to 11.1 gm dry weight m^{-2} at the experimental site.

TABLE 2: MEAN BIOMASS DENSITIES FOR EXPERIMENTAL AND CONTROL REACHES, AVON RIVER, MAY-SEPTEMBER, 1982

Sampling Date	BIOMASS DENSITY (gm dry weight/sq. m.)						Aquatic Plant Species	
	EXPERIMENTAL (71% Shade)			CONTROL (no shading)			(% composition by dry weight)	
	MEAN ¹	MAX	MIN	MEAN ¹	MAX	MIN		
May	10	32.3	90.4	8.6	43.1	89.3	15.1	100
	13	31.2*	137.8	2.2	67.8*	158.2	21.5	100
	17	35.5*	128.1	7.5	108.7*	161.5	26.9	100
	20	11.8*	35.5	0	108.7*	166.8	51.7	100
	24	11.8*	42.0	1.1	132.4*	190.5	45.2	100
	27	14.0*	62.4	2.2	103.3*	266.9	15.1	100
	31	9.7*	35.5	0	47.4*	94.7	17.2	100
	June 03	16.1	38.8	1.1	23.7	62.4	0	100
June	10	14.0*	38.8	0	37.7*	174.4	12.9	100
	17	21.5*	75.3	0	31.2*	84.0	8.6	100
	25	3.2*	10.8	0	9.7*	28.0	0	100
	30	0.9*	4.3	0	4.3*	9.7	0	100
	July 08	1.1	5.4	0	7.5	29.1	0	100
July	15	0.5	4.3	0	5.5	32.3	0	100
	22	6.5*	16.1	0	14.0*	48.4	3.2	100
	29	2.9*	6.5	0	10.3*	20.5	0	85
	Aug. 05	3.8	6.5	1.1	5.2	25.9	0	75
Aug.	12	1.4	4.3	0	4.1	6.5	0	100
	24	6.9	40.9	0	3.8	20.5	0	100
	Sept. 02	4.0	8.6	0	6.5	19.4	0	100
Sept.	09	1.9	4.3	0	2.9	18.3	0	100
	16	10.5*	74.3	0	22.6*	66.7	1.1	85
	22	15.5*	62.3	2.2	49.8*	95.8	8.6	90
	29	10.0*	22.6	1.1	42.2*	52.8	18.3	95
SEASONAL MEAN		11.1		37.2			93.4	6.6

1 Asterisks indicate that experimental and control data were significantly different at a 5% level of confidence. The Mann-Whitney U-test was used to compare sample populations in this analysis.

2 "Others" include Potamogeton natans, Elodea canadensis, Ceratophyllum demersum, and Hydrodictyon sp.

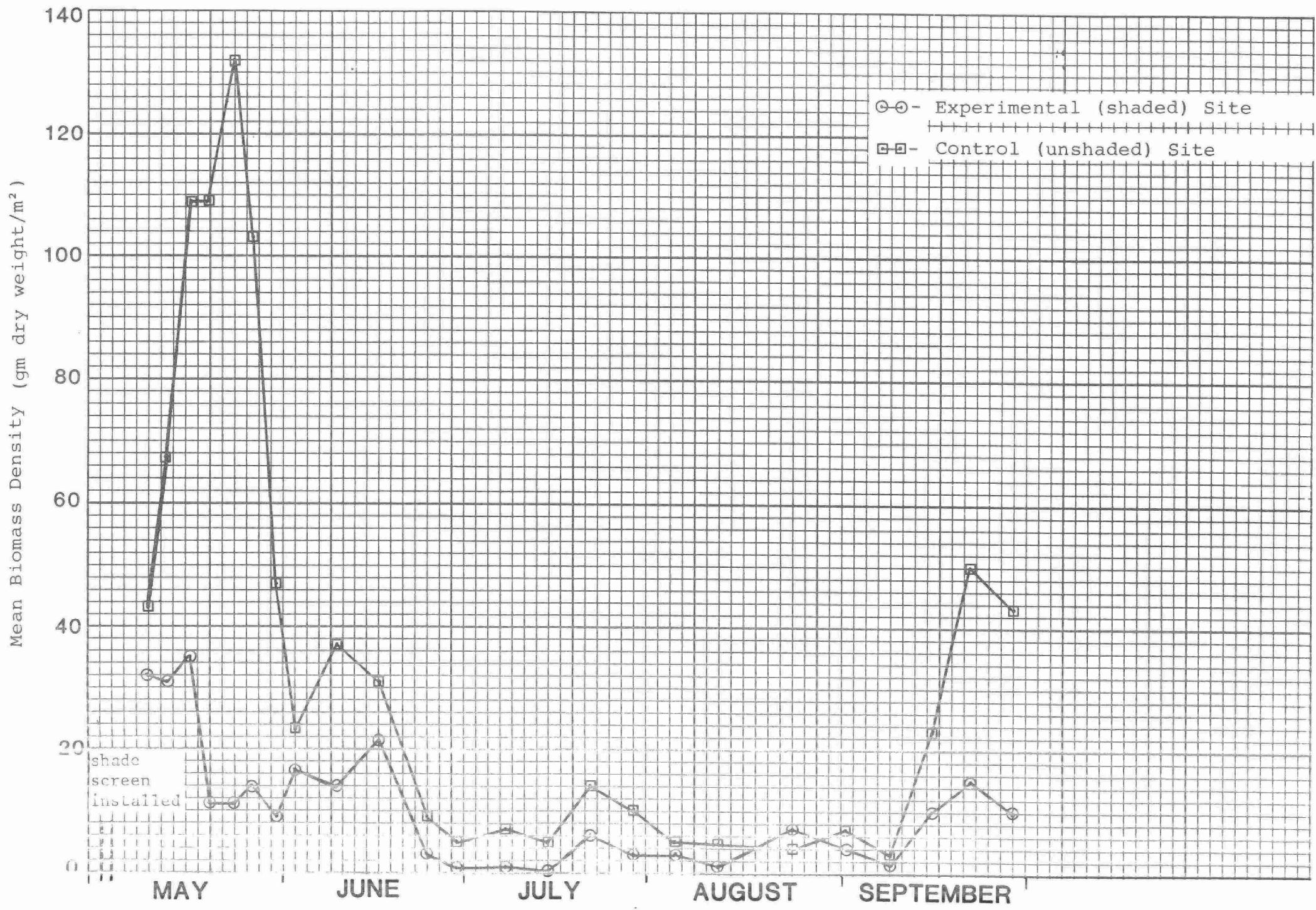


FIGURE 6: MEAN BIOMASS DENSITIES FOR THE EXPERIMENTAL AND CONTROL PEACHES BY SAMPLING DATE, 1992

Mean density in the experimental reach exceeded that in the control reach on only one sampling day, August 24. Since at this time densities are low, normal sampling variability could account for this difference. On other days, mean plant densities in the experimental reach were 9% to 75% of the mean plant densities in the control reach. The largest absolute differences occurred during the peak growth periods in May and early June and again later in September. The lower water temperatures during these periods were ideal for Cladophora growth, and the availability of light became a critical limiting factor.

The effect of light is only important during growth periods. Assuming no other factors are limiting, growth only occurs when the water temperature is favourable. After mid June, growth is inhibited by high water temperatures. Therefore it is expected that the "shade" effect is negligible during this time of no growth. A statistical analysis of the differences between control and experimental sample populations supports this. The analysis was based on a Mann-Whitney U-test of sample populations on each sampling day. It showed significant differences at the 5% level throughout the early and late sampling period which represent growth seasons but only occasionally in July and August during the no-growth period. In all cases of significant difference, the biomass weight at the control reach exceeded that of the experimental reach.

Additional tests were made on the biomass data to assess the uniformity of biomass densities within each reach. This was of particular concern for the experimental reach since the north-east border of that reach received some early morning sunlight when the sun's rays were sufficiently low to reach under the shade canopy.

Sampling data were stratified into the five horizontal blocks shown in Figure 3 and into four 5-foot-wide blocks running the length of the sample reaches. The Mann-Whitney U-test was again used to compare sampling data from the blocks thus defined. No significant differences at a 5% level were identified between any of the sample sets from blocks running either vertically or horizontally; this was true so for both reaches. The biomass growth trend was then removed from the data by division of individual samples using mean biomass levels determined for each sampling day. Tests on blocks within each reach were repeated with this normalized data with the same result, that no significant differences were found between vertically and horizontally defined blocks of data.

Water quality data, summarized in Table 3, indicate nutrient levels that are not likely to be limiting to aquatic plant growth. A concentration of total phosphorus below 0.03 mg/l will eliminate excessive aquatic plant growth* while at concentrations below 0.06 mg/l, the relative rate of photosynthesis of Cladophora will fall**. Observed concentrations of total Phosphorus generally exceeded these values. The typical ratio of nitrogen to phosphorus, in algal organic material 8.75,***, is always exceeded in this river system, so that nitrogen is not expected to be a limiting nutrient either.

* MOE, Rationale for the Establishment of Ontario's Provincial Water Quality Objectives, September 1979.

** R. Walker, D. G. Weatherbe, K. Willson, Aquatic Plant Model - Derivation and Application, Grand River Basin Water Management Study Technical Report Series, Report # 14, November, 1982.

*** Walker et al, *ibid*.

TABLE 3: WATER QUALITY AT THE SITE OF THE
ARTIFICIAL SHADING EXPERIMENT,
AVON RIVER, 1982

Date	May* 13	June* 9	June* 23	July** 8	July** 22	Aug** 5	Aug** 19	Sept** 2	Mean
TOTAL PHOSPHORUS-P(mg/l)	.038	.043	.061	.098	.084	.083	.042	.179	.078
FILTERED REACTIVE PHOSPHORUS-P(mg/l)	.006	.003	.010	.059	.038	.033	.004	.086	.030
TOTAL KJELDAHL NITROGEN-N(mg/l)	.94	.89	.85	.86	.73	.82	.88	1.48	.93
NITRITE PLUS NITRATE-N(mg/l)	1.93	2.42	2.02	.66	.20	.73	.93	1.93	1.35
RATIO OF TOTAL N TO TOTAL P	76	77	47	16	11	19	43	19	29

* Samples on these dates were taken mid-way between the control and experimental reaches.

** Values shown for these dates are the means of data for two samples taken at the control and experimental reaches respectively.

TABLE 4: PLANT TISSUE NUTRIENT
ANALYSIS FOR THE ARTIFICIAL SHADING EXPERIMENT,
AVON RIVER, 1982
(all units are mg/gm)

Date and Reach	Total Phosphorus	Total Nitrogen
May 17 - Control	1.81 + .21	24.96 + 1.98
- Experimental	1.53 + .13	19.37 + 1.76
June 3 - Control	2.71 + .47	26.30 + 3.24
- Experimental	2.65 + .16	23.03 + 1.21
June 9 - Control	2.75 + .23	27.27 + 3.93
- Experimental	2.09 + .22	24.17 + 2.17

Further evidence of the relative abundance of these two nutrients is found in data from the nutrient analysis of plant tissues. Concentrations of phosphorus and nitrogen measured in plant tissue samples collected during the rapid growth periods in early May and June (see Table 4) never fell below 1.3 mg/gm and 13 mg/gm respectively concentrations which are considered to be growth limiting.*

4.2 Field Observations from Naturally Shaded Sites

Field data collected on May 25 from areas naturally shaded by overhanging black willow (*Salix nigra*) are outlined in Table 5. Aquatic biomass densities in colonies of algae found under the trees were 48% to 61% lower than those observed in full sunlight, and algal coverage of the streambed under shade was reduced by 5% to 30%. This suggests an overall reduction of biomass of from 60% to 74%.** The degree of shading provided by these trees ranged from 48% to 83%, as compared to 71% shading provided by the artificial canopy.

Other factors here, such as depth, velocity and substrate type, are quite variable and undoubtedly influence algal growth as well. However, light was the only factor varying consistently in one direction across all four sites. Since biomass densities vary in a similarly consistent manner, light would seem to be a dominant factor influencing aquatic plant growth at these sites.

* Walker et al, op. cit.

** These values are based on a comparison of the unshaded biomass levels to a weighted average of biomass levels in growth and no-growth areas under shade.

TABLE 5: FIELD OBSERVATIONS UNDER NATURAL TREE CANOPIES, THAMES RIVER - MAY 25, 1982

SITE NO.	FULL SUNLIGHT						UNDER TREE CANOPY						CHANNEL BOTTOM	
	BIOMASS		WATER DEPTH (cm)	WATER VELOCITY (cm/sec)	% LIGHT PENETRATION		BIOMASS		WATER DEPTH (cm)	WATER VELOCITY (cm/sec)	% LIGHT PENETRATION			
	gm/m ²	% cover			ABOVE WATER	BELOW WATER	gm/m ²	% cover			ABOVE WATER	BELOW WATER		
1	9.0	100.0	36.2	27.10	100.0	70.0	9.0	80.0	26.7	3.44	33.3	16.7	Limestone overlain with silt and clay sediments	
2	24.6	100.0	22.3	50.78	100.0	68.0	12.9	70.0	16.1	20.60	42.7	30.5	Limestone overlain with silt and clay sediments	
3	30.5	100.0	31.0	63.83	100.0	64.6	12.9	95.0	15.0	64.98	53.3	not avail.	Stones, cobbles, gravel	
4	9.7	100.0	24.7	48.43	100.0	65.0	3.8	70.0	24.7	108.20	16.7	11.1	Gravel, cobbles, boulders	

5.0 CONCLUSIONS

Several factors influence the growth of aquatic plants in natural environments: light, temperature, nutrient flux, substrate, etc. By artificially reducing one of these factors, light, nuisance aquatic plant growth was reduced during peak growth seasons by 54% to 91%. Over the full sampling period, the standing crop of biomass was on average 70% lower under the shade canopy than in full sunlight. An average light reduction of 71% produced these results. Differences were smallest in the later part of summer when water temperatures were too warm to sustain a population of Cladophora and total biomass levels for other species were negligible. At sites having natural tree canopies in full leaf, a 48% to 83% reduction in incident sunlight was observed under the canopy. This was associated with reductions of biomass that were comparable to those with the artificial shade, ranging between 60% and 74%. Other factors such as water temperature also affected biomass density levels at these locations.

The potential for practical application arising out of this experiment lies in the use of tree shade along shallow eutrophic rivers to control aquatic plant growth. However, a degree of caution is warranted in implementing such an application, since impacts of bank side tree planting other than aquatic plant control have not been considered in this report. These could include reduction of low flows due to evapotranspiration from tree leaves, impedance of high flows by tree trunks, stream bank erosion due to the loss of ground cover plants that cannot tolerate shade, and reduction of ambient water temperatures due to shading of the water surface. Certain of these impacts are addressed in a companion technical report. "Design of an Arboreal Shade Project to Control Aquatic Plant Growth", (D. Hayman, M. Fortin, M. Seto. SAREMP Technical Report S-15, 1983)

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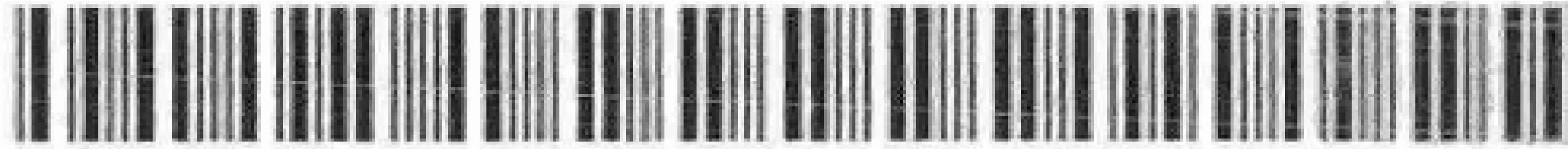
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STRATFORD-AVON RIVER ENVIRONMENTAL MANAGEMENT PROJECT
LIST OF TECHNICAL REPORTS

- S-1 Impact of Stratford City Impoundments on Water Quality in the Avon River
- S-2 Physical Characteristics of the Avon River
- S-3 Water Quality Monitoring of the Avon River - 1980, 1981
- S-4 Experimental Efforts to Inject Pure Oxygen into the Avon River
- S-5 Experimental Efforts to Aerate the Avon River with Small Instream Dams
- S-6 Growth of Aquatic Plants in the Avon River
- S-7 Alternative Methods of Reducing Aquatic Plant Growth in the Avon River
- S-8 Dispersion of the Stratford Sewage Treatment Plant Effluent into the Avon River
- S-9 Avon River Instream Water Quality Modelling
- S-10 Fisheries of the Avon River
- S-11 Comparison of Avon River Water Quality During Wet and Dry Weather Conditions
- S-12 Phosphorus Bioavailability of the Avon River
- S-13 A Feasibility Study for Augmenting Avon River Flow by Ground Water
- S-14 Experiments to Control Aquatic Plant Growth by Shading
- S-15 Design of an Arboreal Shade Project to Control Aquatic Plant Growth

- U-1 Urban Pollution Control Strategy for Stratford, Ontario - An Overview
- U-2 Inflow/Infiltration Isolation Analysis
- U-3 Characterization of Urban Dry Weather Loadings
- U-4 Advanced Phosphorus Control at the Stratford WPCP
- U-5 Municipal Experience in Inflow Control Through Removal of Household Roof Leaders
- U-6 Analysis and Control of Wet Weather Sanitary Flows
- U-7 Characterization and Control of Urban Runoff
- U-8 Analysis of Disinfection Alternatives

- R-1 Agricultural Impacts on the Avon River - An Overview
- R-2 Earth Berms and Drop Inlet Structures
- R-3 Demonstration of Improved Livestock and Manure Management Techniques in a Swine operation
- R-4 Identification of Priority Management Areas in the Avon River
- R-5 Occurrence and Control of Soil Erosion and Fluvial Sedimentation in Selected Basins of the Thames River Watershed
- R-6 Open Drain Improvement
- R-7 Grassed Waterway Demonstration Projects
- R-8 The Controlled Access of Livestock to Open Water Courses
- R-9 Physical Characteristics and Land Uses of the Avon River Drainage Basin
- R-10 Stripcropping Demonstration Project
- R-11 Water Quality Monitoring of Agricultural Diffuse Sources
- R-12 Comparative Tillage Trials
- R-13 Sediment Basin Demonstration Project
- R-14 Evaluation of Tillage Demonstration Using Sediment Traps
- R-15 Statistical Modelling of Instream Phosphorus
- R-16 Gully Erosion Control Demonstration Project
- R-17 Institutional Framework for the Control of Diffuse Agricultural Sources of Water Pollution
- R-18 Cropping-Income Impacts of Management Measures to Control Soil Loss
- R-19 An Intensive Water Quality Survey of Stream Cattle Access Sites



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